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The Effects of Application of Molybdenum and Concentration of Molybdenum in the Seed on the Yield and the Concentration of Molybdenum in the Tissue of Soybeans, Glycine Max (L.) Merr.

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ABSTRACT

Field experiments were conducted in 1970 and 1971 to determine the effects of different rates and methods of application of molybdenum (Mo) on the yield and concentration of Mo in soybean seed, Glycine max (L.) Merr. Cultivar Bienville. The experiments were conducted on Olivier silt loam soil. The soil at the 1970 experimental site had a pH of 7.0; the soil at the 1971 site had a pH of 5.8. Soil applications were 8 and 16 ounces of Mo per acre (560 g/ha to 1120 g/ha) applied immediately after planting. Application at the rate of 1/4 ounce of Mo per acre (17.47 g/ha) was made to seed prior to inoculation and planting. Foliar applications at the rate of 1/4 ounce per acre (17.47 g/ha) were made when plants were 10 inches (25 cm) tall, at the early bloom stage and at early fruit set.

Another field experiment with seed that varied in the concentration of Mo from 0.17 ppm to 30.19 ppm was conducted on an Olivier silt loam, pH 6.9, to determine if the concentration of Mo in the seed affected yield. Seed containing 0.17, 0.52, 0.96, and 18.3 ppm Mo were compared with seed that contained 4.27 ppm of Mo and treated with 1/4 ounce of Mo per acre (17.47 g/ha) for production of dry matter and concentration of Mo in soybean plants grown in the greenhouse. The soil used was an Hebert fine sandy loam, pH 4.2.

The application of Mo did not significantly increase the yield of soybeans grown on the Olivier silt loam soils at pH 7.0 and pH 5.8 in 1970 and 1971. However, the concentration of Mo in the seed was significantly increased by different rates and methods of application of Mo.

The application of Mo as a combination of a soil, seed, and foliar treatment resulted in a significantly higher concentration of Mo in the soybean seed than did either of these treatments alone. Soil reaction (pH) influenced the uptake and the concentration of Mo in the seed. Seed produced on the soil at pH 7.0 contained over twice as much Mo as did seed produced on the soil at pH 5.8. The time and method of application of Mo had a greater effect on the concentration of Mo in the seed than did the rate of Mo used. Mo applied to the foliage of the soybean plants at the early pod-set stage of growth resulted in seed that contained the highest concentration of Mo.

The concentration of Mo in seed had no measurable effect on the yield of soybeans grown on the Olivier silt loam, pH 6.9 in the investigation conducted in the field. However, under greenhouse conditions on Hebert fine sandy loam, pH 4.2, seed that contained 0.17 ppm of Mo produced significantly smaller amounts of dry matter than did seed that contained 0.52 ppm of Mo. The concentration of Mo in the tissue of plants grown from seed that contained 4.27 ppm of Mo and treated with 1/4 ounce of Mo per acre (17.5 g/ha) was significantly higher than that in plants grown from seed that contained less than 1 ppm of Mo. Plants grown from seed that contained 18.3 ppm of Mo had the highest concentration of Mo in the tissue.

INTRODUCTION

Molybdenum (Mo) as a plant nutrient is one of the latest to have attained significance in soil fertility. It has only been within the last several years that the use of Mo has become firmly established as a recommended practice on certain soil-crop complexes. Its use has expanded rapidly during the last decade and it is well on the way to becoming a major micronutrient for crop production.

According to Stout and Johnson (91), Mo as a plant nutrient element is required in the smallest quantities for plant growth. In fact, Thompson and Anthony (92) refer to Mo as the mighty midget because most crops require less than 0.5 ppm in their tissue for good growth.

The beneficial effect of Mo on the growth of legumes was first reported in 1937 by Bortels (21). The first evidence of a physiological role of Mo as an essential plant nutrient was provided by Steinberg (88) in 1936. Two years later, Arnon and Stout (12) demonstrated that tomato plants could not complete their life cycle when growing on highly purified water cultures unless supplemented with Mo. Piper (71) in 1940 described Mo deficiency symptoms in oats. The careful work of Arnon and Stout (12) and Piper (71) with controlled nutrient solutions demonstrated that Mo was absolutely essential for higher plants. Fertilization with this element increased the yield of more than 20 crops. Among these are cauliflower, cabbage, mustard, sugar beet, celery, radish, carrot, potatoes, tomatoes, alsike clover, red clover, white clover, subterranean clover, alfalfa, pea, bean, rye, barley

(6, 45, 47, 90, 91), citrus (97) and soybeans (11, 43, 68, 84, 93).

In 1942 Anderson (3) reported a significant response of subterranean clover, Trifolium subterraneum, and alfalfa, Medicago sativa, to Mo on South Australian soils. Since that time a number of workers have been engaged in Mo research on legume crops.

The number of states in the United States reporting Mo deficiencies for one or more crops increased from 13 in 1955 (83) to 21 by 1962 (19). Since that time yield increases of soybeans have been reported from the use of Mo on acid soils by most of the states in the Southern region of the United States (11, 35, 52, 53).

Thompson and Adams (94) reported yield increases from 1 to 7 bushels of soybeans per acre, (63 kg/ha to 439 kg/ha) following the application of Mo to soybean seed in Arkansas. Yield increases of from 1.4 bushels per acre (94 kg/ha) to 11.7 bushels per acre (786 kg/ha) have been attributed to the application of Mo as a seed treatment on outfield experiments in Louisiana (84). Yield increases have not been observed on near neutral to alkaline soils, or on acid soils that had been limed (58, 85).

Several researchers have investigated the Mo content of seed and the possibility of the seed supplying the growing plant with sufficient Mo for maximum yields. Investigators in Georgia (39, 44) found that the Mo requirement of soybeans growing on a Mo deficient soil could be met by using seed containing high levels of Mo. Lavy and Barber (55) reported that there was no significant yield response to applied Mo when the soybean seed contained more than 1.6 ppm Mo. Peterson and Purvis (70) showed that in some large seeded legumes including soybeans, it was necessary to grow one or more generations in Mo-deficient media before response to the element could be demonstrated.

The application of Mo would not be required for the production of soybeans if a high concentration of Mo in soybean seed could supply the needed Mo. This investigation was undertaken to determine (1) the effects of Mo treatments and methods of applications on yield and the concentration of Mo in soybean seed produced, and (2) to determine the effects of the concentration of Mo in soybean seed and Mo treated soybean seed on the production of dry matter and the Mo composition of the soybean plant, *Glycine max* (L.) Merr., Cultivar Bienville.

REVIEW OF LITERATURE

Forms and Distribution of Mo in Soils

Discovery of Mo as an element was made by Hjelm (36) in 1782. The average proportion of Mo in the igneous rocks of the earth's crust is about 10^{-6} percent. According to Northcott (64) the principal Mo minerals and their compositions are:

Mineral	Composition
Molybdenite	MoS_2
Wulfenite	$PbMoO_3$
Molybdite	$FeO_3 \cdot 3MoO_3 + H_2O$
Provellite	$Ca(MoW)O_4$
Ilsemannite	$Mo_2 \cdot 4MoO_3$
Bilonesite	$MgMoO_4$
Pateraite	$CoMoO_4$

Soil Mo has been classified by several workers. Barshad (14) indicated that the Mo in soils is present as a soluble molybdate salt, as a part of the organic matter, and possibly as an exchangable molybdate anion. Amin and Joham (2) reported that it is possible to fractionate soil Mo roughly as: 1. water soluble, consisting largely of soluble salts of Mo which are available to plants, 2. ammonium hydroxide soluble or readily complexable Mo, which is not available as such, but can become easily available by reacting with cations present in the soil, and 3. oxidizable Mo, which is not available to plants as such and requires oxidation before it is converted to a readily available form. These fractions were noted to correspond closely to the solubilities of 1. molybdate salts, 2. Mo trioxide, and 3. reduced oxides of Mo in atta-clay-Mo mixtures.

Davies (25) classified soil Mo into four groups:

(1) Unavailable (held within the crystal lattice of primary and secondary minerals);

(2) Conditionally available (retained as the MoO_4 anion by clay minerals and available to a greater or lesser degree depending on pH and probably phosphate status);

(3) In organic matter;

(4) Water soluble.

Robinson et al (80) analyzed 40 soil samples in the United States and found 95 percent of them ranged between 0.6 to 3.5 ppm Mo. The maximum found was 31.5 ppm. The average Mo content of soils according to Robinson and Alexandria (81) is 2.5 ppm. Eighteen New Jersey soils were found to vary between 0.8 and 3.3 ppm with an average of 1.44 ppm according to Evans and Purvis (32).

Excessive amounts of Mo have been found in California, Oregon and Florida (83). Soil containing 75 ppm of Mo has been reported in Hawaii (16).

The total content of Mo in the soil is of little value with respect to the amount of the element available to plants (37). The reaction of the soil has a great influence on the uptake of Mo by plants because of the increased solubility of Mo in neutral to alkaline soils. The Mo is apparently unavailable to plants in acid soils. Several workers have reported response to Mo in acid soils (8, 17, 24, 33, 55, 57, 58, 68, 84, 85, 93) and liming acid soils has corrected Mo deficiencies (7, 11, 17, 33, 68, 82, 85, 93).

Factors Affecting the Uptake and Response to Mo

Soil reaction, pH, and the N, P, S, and Mn levels in soils, and plant species affect the "availability" and uptake of Mo by plants (6, 15, 26, 89, 90, 92).

The soil reaction probably exerts the greatest influence on the solubility and uptake of Mo by plants. Sparr et al (86) and Lucas et al (57) indicated that the "availability" of Mo is reduced by high soil acidity and by the presence of Fe and Al oxides. These investigations reported that Mo is the only micronutrient element essential for plant growth that is less soluble in an acid soil than in an alkaline soil. According to their report, Mo is readily fixed in acid soils on the surface of Fe and Al oxide particles where it is unavailable to growing plants. Stout et al (89) reported that in a culture solution the uptake of Mo was favored by an acid reaction. The reverse of this was true in soils (14, 30). In 1962, Reisenauer et al (77) reported that the Mo reacted with Fe compounds in the soil in the following manner:

(1) $Fe_2O_3 + 3H_2O \rightleftharpoons 2Fe(OH)_3$

(2) $2Fe(OH)_3 + 3\ Na_2MoO_4 + 6HCl \rightleftharpoons Fe_2(MoO_4)_3 + 6NaCl + 6H_2O$

(3) $Fe_2O_3 + 3Na_2MoO_4 + 6HCl \rightleftharpoons Fe_2(MoO_4)_3 + NaCl + 3H_2O$

The quantity of Mo absorbed by Fe_2O_3 was measured as 1 milli-mole of Mo per gram of $Fe_2O_3 \cdot x\ H_2O$ (35). Jones (50, 51) found that hydrous Fe oxides absorb Mo much more strongly than Al oxides. According to Ellis and Knezek (28) the forms of Fe-oxides and hydroxides in soil systems are very complex and these authors were of the opinion that a variety of complexes may be formed. The first absorption of Mo by soils may be through covalent bonding to surface hydroxyls present or an exchange for surface hydroxyls. Later crystallization of Fe molybdate minerals with discrete molar ratios may occur. Jones (50) demonstrated this in the laboratory. Although it is less likely to occur in soils where the Mo concentrations are low, it is a very plausible mechanism even in natural soils.

According to Anderson (6) liming acid soils has pronounced effects on the response of plants to Mo. On some soils responses to application of Mo do not occur if lime has been applied. On other soils responses to application of Mo occur only when some lime has been applied, and on some soils under certain cropping conditions, lime may have little or no influence on the response to added Mo.

One of the primary effects of lime is to correct the deficiency of Mo, either partly or completely, by increasing the availability of Mo in the soil (8, 66). Anderson et al (7) found a significant correlation between liming and the uptake of Mo by peanuts. A number of other workers have demonstrated that liming increased the Mo content of plant tissue (10, 15, 30, 39, 48, 80). Price and Moschler (73) reported that the concentration of Mo in several crops was increased by lime applied seven to nine years previously. The Mo content of alfalfa, crimson clover and Austrian winter peas was increased six-to-eleven-fold when a soil was limed from pH 7.0 to 7.6, according to Robinson et al (80). They reported that heavy lime applications did not increase the concentration of Mo in ryegrass nearly as much as it did in the legumes.

The uptake of applied Mo can be increased by liming (1, 30, 39, 91). Gurley and Giddens (30) reported that high levels of applied Mo resulted in an excessive accumulation of Mo (48 ppm) in soybean seed.

Nugent et al (65) showed an increase in the concentration of Mo in the leaves of soybean plants grown on soils that had been recently limed. Dharmaputra (27) reported that the Mo concentration in soybean leaves was the highest when the Mo was applied with lime.

The nitrogen level and the source of nitrogen affects the response of plants to applied Mo or "available" Mo in the soil. The use of Mo on legumes is primarily to increase symbiotic nitrogen fixation, and the responses of clover to Mo are greater where nitrogen is deficient (6). Anderson and Spencer (9) reported that Mo increased the yield of clover from 2.8 grams to 7.4 grams per pot when no N was applied, and only from 6.3 grams to 7.8 grams per pot in the presence of N.

Mo uptake was increased by the application of P to soils according to several workers (8, 15, 54, 89). Anderson and Ortel (8) reported that subterranean clover grown on Mo responsive soils made vigorous growth when phosphate and Mo were applied together; response to Mo increased as the phosphate level approached the optimum level.

According to Barshad (15) the application of phosphoric acid greatly increased the Mo content of ladino clover. True and Shrewsbury (95) reported that the addition of Mo to the P fertilizer significantly increased the fresh weight yields of subterranean clover, bur clover, madrid sweet clover, narrow leaf trefoil, hairy vetch, and the blue panic.

Stout et al (89) reported the Mo content in the plant tissue of subterranean clover was increased ten- to thirty-fold over the tissue of plants grown on soils that did not receive phosphorus.

The relation between the soil anions, molybdate and phosphate, may be associated with the formation of a complex phospho-molybdate anion which is absorbed more easily by the plant than the molybdate anion alone according to Barshad (15).

In contrast to P, the uptake of Mo by plants is reduced by the application of S to the soil. Stout et al (89) explained the effect as a direct competetion between two di-valent anions of the same size. S applied as $CaSO_4 \cdot 2H_2O$ reduced the yield and N content of peas, but the application of Mo overcame the depressive effect of S (79).

The Mo concentration in the top and roots of Brussels sprouts was drastically reduced by the application of S according to Gupta and Munro (38). The S was applied as ammonium sulfate and did not alter the soil reaction.

According to Ovellette (67) and Widdowson (96), the application of superphosphate, which contained 50 percent $CaSO_4 \cdot 2H_2O$, has decreased the Mo uptake by plants.

Plant species vary greatly in their ability to absorb Mo from the soil. For example, Barshad (13) found the concentration of Mo in Ladino clover to be 123 ppm and Rhodesgrass 17 ppm after 66 days of growth. Stout and Johnson (90) reported the uptake of Mo in micrograms by the following plants after eight weeks of growth in pots: wheat, 0.11; oats, 0.17; barley, 0.28; cowpeas, 0.67; white clover, 0.83; tomato, 0.87; and sweet corn, 2.43.

The Role of Mo in Plants

In a recent review Hagstrom (40) stated that Mo plays several roles in plant growth; of these roles its essentiality for the process of N fixation by nodule bacteria is one of the most important. Mo is also essential for the enzymatic reaction involved in reducing nitrate N to amino N. According to Price (72) Mo is contained in two plant enzymes, namely nitrogenase and nitrate reductase. Evans (29) reports that there is strong evidence that Mo may play a role in the inhibition of plant phosphatase.

In 1930 Bortels (20) found that the aerobic N-fixing bacteria, Azotobacter chroococcum, responded to Mo. He also showed that the growth and N fixation by legumes were increased by the application of Mo (21).

Mulder (60) reported that peas grown in the absence of Mo formed many modules, but the N-fixing capacity of the nodules was greatly reduced. Beeking (18) reported that in pot experiments with alder (Alnus glutinosa (L.) Gaertin) plants receiving Mo showed a 370 percent increase in total N content over untreated plants. He showed that Mo treated plants have a much higher dry weight of nodule tissue.

Several workers (4, 32, 34, 68) have reported that Mo increased the N concentration in legumes. Hagstrom and Berger (42) showed that 2 pounds of Na molybdate per acre on a soil that contained 0.26 to 0.47 ppm total Mo increased the yield, the nodulation and the N content of soybeans. According to Anderson (5) Mo deficiency will inhibit symbiotic N fixation.

The first evidence that Mo was essential for the reduction of nitrates in plants was shown in 1936 by Steinberg (88). Mulder (60) reported that barley and tomato plants fertilized with nitrate N in the absence of Mo were pale green and contained a high concentration of nitrate and a low concentration of protein N compared to Mo treated plants. Research conducted by Mulder indicated that Mo was essential for a chemical reaction involved directly in the reduction of nitrate N. Spencer and Wood (87) presented eveidence that Mo was specifically involved in the conversion of nitrate to nitrite.

Meagher et al (59) reported that garden peas and dwarf horticultural beans grown with nitrate as the N source, required Mo for the completion of their life cycle. Evans et al (31) found that an accumulation of nitrates occurred in alfalfa plants that were deficient in Mo.

According to Nicholas and Mason (63) the conversion of nitrate to ammonia is essentially the result of a series of chemical reactions by which the N atom of nitrate with an oxidation number of +5 is ultimately reduced to an oxidation state of -3, as represented by ammonia, a net change of 8 electrons. They showed that Mo is the metallic portion of the nitrate reductase in soybean leaves.

Mo Content of Soils and Plants and Response to Mo Fertilization

Since crop yields are not related to the total Mo content of soils (37), a variety of extractants have been used in attempts to assess so called "available" Mo. According to Davies (25) neutral normal ammonium acetate, normal ammonium acetate adjusted to pH 9, normal ammonium hydroxide, and water have been used to extract Mo.

Barshad (14) reported that the concentration of Mo in the plant was roughly proportional to the water soluble Mo in the soil between pH 4.7 and 7.5. Above this range, water soluble Mo increased but plant uptake decreased. Lowe and Massey (56) reported that hot water extractable Mo was better correlated with plant uptake than that extracted by ammonium oxalate. Haley and Melsted (43) indicated that the only forms of soil Mo that gave statistically significant correlation with plant composition were the forms extracted by sodium hydroxide and acid ammonium oxalate. Grigg (37) reported that the acid ammonium oxalate extractable level of Mo below which field responses may be expected to occur for pasture is 0.05 ppm for pH 6.5, 0.10 at pH 6.0, 0.15 at pH 5.5 and 0.20 at pH 5.0.

Dharmaputra (27) indicated that the response to application of Mo by soybeans was generally obtained when the value of the soil pH + (10 x Extractable Mo) was less than 7.5.

A biossay method for determining the "available" Mo content in soils using Aspergillus niger has been used by several workers (60, 62).

Attempts to relate Mo content of plants to yield have been made by a number of researchers (26, 43, 55, 75). Reisenauer (75) reported that yield increases of alfalfa from Mo fertilization would not be expected when the concentration of Mo in the leaves exceeded 0.5 ppm. Evans and Purvis (32) reported yield increases of 13 percent and 9 percent from Mo fertilization when the concentrations of Mo in the tops of alfalfa plants were 0.77 and 0.85 ppm, respectively. deMooy (26) also reported yield responses when the concentration of Mo in the leaves of alfalfa plants was above 0.5 ppm. The amount of Mo in clover tops making near optimum growth was as little as 1 ppm on a dry weight basis according to Oertel et al (66). Barshad (14) reported that the Mo content in plants increases with age of plant.

Since the seed of soybeans contain about twice as much Mo as either the stem or the leaves, the concentration of Mo in the seed is considered to be a good indicator of the "availability" of Mo according to Lavy and Barber (55). They obtained yield increases of 0.7 to 7.6 bu. per acre where the soil pH level was 6.0 or below and the concentration of Mo in the seed was 1.2 ppm or below. They obtained no yield response to added Mo when the concentration of Mo in the seed exceeded 1.6 ppm. Hagstrom and Berger (41) observed that peas responded to soil application of Mo when the pea seed contained 0.17 ppm Mo but not when the seed contained 0.65 ppm.

Lavy and Barber (55) reported that the relatively large concentration of Mo in seed assured more precision in determining when a Mo response may be expected than did other plant parts.

Supplying Mo for Plant Needs

Several methods have been employed in supplying Mo for plants. These have included application of Mo to the soil, directly to the seed and to the foliage of plants as aqueous solution. Soil application of 1 1/3 ounces (93 g/ha) of Mo per acre increased soybean yields from 234 to 300 pounds per acre (269 to 336 kg/ha) on acid soils in Iowa (26). Murphy and Walsh (61) stated that treating the seed was the most common method of applying Mo. Several workers have obtained yield increases by applying Mo as a seed treatment (11, 58, 65, 84, 85, 93).

Reisenauer (78) indicated that seed application of Mo was more effective than soil application for peas. He found that the seed treatment tended to increase the molybdenum content of the plant much more than did the soil treatment. Boswell and Anderson (22) compared a seed treatment with a foliar application at several stages of growth of soybean plants growth on seven soils in Georgia. When soybean plants were sprayed when eight inches tall (about 20 cm), they found seed and foliar spray treatments to be equally effective. Foliar application at bloom or early pod was significantly less effective than earlier applications made when plants were 10 cm tall. Parker and Harris (68) showed that the check, seed and foliar spray Mo treatments resulted in soybean yields of 37, 40, and 42 bushels (2500, 2720 and 2870 kg/ha) per acre respectively.

In some experiments the Mo needs on Mo-deficient soils have been supplied in the seed of large seeded legumes (39, 41, 44, 46, 59). Hewett et al (46) reported that seed reserves played an important part in the incidence of Mo deficiencies in peas and beans. Meagher et al (59) reported that garden peas and dwarf beans may contain a sufficient amount of Mo to meet the plants needs. According to Hagstrom and Berger (41) pea seed containing 0.65 ppm Mo did not respond to applied Mo. Gurley and Giddens (39) showed that the Mo requirement of soybeans grown on Mo-deficient soils could be met by using seed containing high levels of Mo. They concluded that a practical way of meeting the Mo requirement of molybdenum deficient areas would be to apply a foliar application of Mo on the seed crop and grow the seed crop on soils with a pH of 6.5 or above. They found accumulations of up to 48 ppm Mo in soybean seed. This could be toxic if seed were fed to livestock.

Harris et al (44) collected seed lots in Georgia that ranged from 0.6 to 2.5 ppm Mo. Plants produced from all these seed lots responded to added Mo. Plantings from one seed lot containing 22.4 ppm Mo did not respond to added Mo.

MATERIALS AND METHODS

Field and greenhouse investigations were conducted during a two-year period, 1970 and 1971, to determine the effects of different rates and methods of applying Mo on the yield, on the production of dry matter, and on the concentration of Mo in the tissue of Bienville soybean plants, Glycine max (L.) Merr., grown on Olivier silt loam and Hebert fine sandy loams. Investigations were also conducted in the field and in the greenhouse to determine the influence of different levels of Mo in the seed of Bienville soybeans on the yield and on the concentration of Mo in the tissue of plants grown on an Olivier silt loam and on a Hebert fine sandy loam.

Field Investigations

An experiment was initiated in 1970 to determine the effects of Mo applied to soil, to seed, as a foliar treatment and a combination of these treatments, on the yield and concentration of Mo in the seed. The soil was an Olivier silt loam located on the Burden Research Plantation at Baton Rouge.

The Mo treatments and methods of application are presented in Table 1. The source of Mo was reagent grade sodium molybdate containing 39.65 percent Mo. The Mo was applied to the seed in an aqueous solution prior to inoculation and immediately before planting. The Mo and the seed were mixed thoroughly to insure that the material came into contact with each seed. The Mo was applied to the soil on the surface in an eighteen-inch band using an aqueous solution

Table 1. Mo treatments used in field experiments.

Identification Code	Method of Application	Mo[1/] Application Rate		Time of Application
		oz/acre	g/ha	
A	Check	0	17.5	
B	Seed	1/4	17.5	At planting
C	Soil	8	561.0	Before planting - banded
D	Foliar	1/4	17.5	When plants were 10" tall (25 cm)
E	Foliar	1/4	17.5	When plants were 10" tall (25 cm)
	Foliar	1/4	17.5	Early bloom stage
F	Foliar	1/4	17.5	When plants were 10" tall (25 cm)
	Foliar	1/4	17.5	Early bloom stage
	Foliar	1/4	17.5	Early fruit set
G	Soil	8	561.0	Before planting - banded
	Seed	1/4	17.5	At planting
H	Soil	8	561.0	Before planting - banded
	Foliar	1/4	17.5	When plants were 10" tall (25 cm)
	Foliar	1/4	17.5	Early bloom stage
	Foliar	1/4	17.5	Early fruit set
I	Soil	8	561.0	Before planting - banded
	Seed	1/4	17.5	At planting
	Foliar	1/4	17.5	When plants were 10" tall (25 cm)
	Foliar	1/4	17.5	Early bloom stage
	Foliar	1/4	17.5	At planting
J	Soil	16	1122.0	Before planting - banded
	Seed	1/4	17.5	At planting
	Foliar	1/4	17.5	When plants were 10" tall (25 cm)
	Foliar	1/4	17.5	Early bloom stage
	Foliar	1/4	17.5	Early fruit set

[1/] Mo as $Na_2MoO_4 \cdot 2H_2O$, 39.65 percent Mo, was the source of Mo in all treatments. Soybean seed were inoculated prior to seedling.

immediately following planting. The foliar application of Mo was made in an aqueous solution when the plants were 10 inches tall (25 cm), at the early bloom stage and when plants were setting fruit, or combinations of these foliar treatments.

The untreated Olivier silt loam soil had a pH 7.0. The soil contained 1280 ppm of extractable Ca, 264 ppm Mg, 57 ppm P, 80 ppm K, and 0.99 percent organic matter. The soil was analyzed by the Louisiana State University and Agricultural & Mechanical College Soil Testing Laboratory.

The experimental area was fertilized with 250 pounds of an 0-26-26 fertilizer per acre before seeding. This is equivalent to 28.1 pounds of P and 54.1 pounds of K per acre (31 kg P/ha and 61 kg K/ha). Lasso was used as a broadcast application at the rate of 2.5 pounds per acre (2.8 kg/ha) prior to planting for the control of weeds and grasses. Bienville soybeans were planted at the rate of 45 pounds of seed per acre (50 kg/ha) on June 9, 1970. The soybeans were harvested with a combine on October 30, 1970.

The ten Mo treatments were arranged in a randomized complete block design with five replications of each treatment.

The experiment was continued on an Olivier silt loam in 1971, however, due to a crop rotational program a different site was selected.

The untreated Olivier silt loam soil had a pH of 5.8. The soil contained 640 ppm of extractable Ca, 150 ppm Mg, 49 ppm P, 200 ppm K, and 1.17 percent organic matter. Lasso was applied as a broadcast application at the rate of 2.5 pounds per acre (2.8 kg/ha) prior to planting for the control of weeds and grasses. The area was fertilized with 200 pounds of an 8-24-24 fertilizer per acre before planting. The fertilizer supplied 16 pounds of N, 21 pounds of P, and 40 pounds of K per acre (18 kg N/ha, 23 kg P/ha, and 45 kg K/ha).

Bienville soybeans were seeded at the rate of 45 pounds per acre (50 kg/ha) on May 19, 1971. The soybeans were harvested on October 28, 1971. The experimental design used was a randomized complete block with five replications of each of the ten treatments.

Plot yields for each treatment in the two experiments were recorded and sub-samples of seed harvested from each treatment plot in replications 1, 3, and 5 were taken and stored in cloth bags for chemical analysis.

Another field experiment was conducted at the Burden Research Plantation in 1971 on an Olivier silt loam to determine the influence of seed containing different concentration of Mo on the yield of Bienville soybeans. Seed containing different concentrations of Mo were compared to seed treated with 1/4 ounce of Mo per acre (17.5 g/ha). Ten treatments were used in a randomized complete block design with five replications of each treatment. The concentrations of Mo in the seed are presented in Table 2. The seed identified as S-1, S-2, S-3, S-4, and S-5 were obtained from plants grown on acid soils at the Perkins Road Experiment Station (69). The seed identified as S-6, S-7, S-8, and S-9 were selected from plants that had received varying rates of Mo applied the previous year. Seed identified as S-10 were obtained from the Perkins Road Experiment Station.

The untreated Olivier silt loam soil used to determine the influence of concentration of Mo in the Bienville seed on the yield

Table 2. Concentration of Mo in Bienville soybean seed used in the field experiment.

Seed Identification	Mo Concentration
	ppm
S-1	0.17
S-2	0.29
S-3	0.52
S-4	0.61
S-5	0.96
S-6	5.00
S-7	20.02
S-8	18.30
S-9	30.19
S-10	4.27[1/]

[1/] Mo as $Na_2MoO_4 \cdot 2H_2O$, 39.65 percent Mo, was applied at a rate of 1/4 ounce Mo per acre. Soybean seed were treated with Mo prior to inoculation.

had a pH of 6.9. The soil contained 1600 ppm extractable Ca, 603 ppm Mg, 113 ppm P, 90 ppm K, and 0.96 percent organic matter.

The soil received 200 pounds of an 8-24-24 fertilizer per acre before planting. The fertilizer supplied 16 pounds of N, 21 pounds of P, and 40 pounds of K per acre (18 kg N/ha, 23 kg P/ha, and 45 kg K/ha). Lasso was applied broadcast at the rate of 2.5 pounds per acre (2.8 kg/ha) prior to planting for weed and grass control.

The plots were seeded on June 6, 1971. Due to dry weather a stand was not obtained of replications 3, 4, and 5. These replications were reseeded on June 24, 1971. The seeding rate was 45 pounds per acre (50 kg/ha). Plots were combined on October 28, 1971.

Greenhouse Investigations

Bienville soybean seed that contained different concentrations of Mo were used in the greenhouse investigations. The seed contained 0.17 ppm, 0.52 ppm, 0.96 ppm, 4.24 ppm, and 18.3 ppm of Mo. The seed that contained 4.27 ppm of Mo received an application of Mo at the rate equivalent to 1/4 ounce per acre (17.5 g/ha) when a seeding rate of 45 pounds per acre (50 kg/ha) was used. Exactly 790 mg of Mo as Na molybdate was applied to five pounds of soybean seed to obtain the desired amount of Mo. The Mo was thoroughly mixed with the seed prior to inoculation and immediately before planting.

The soil used in the greenhouse investigation was a Hebert fine sandy loam obtained from the E. C. Magee farm in Caldwell Parish. A field experiment conducted in 1966 indicated that soybeans grown on the Hebert soil responded to applied Mo (84). The untreated soil had a pH of 4.2. The soil contained 200 ppm of extractable Ca, 103 ppm of Mg, 200 ppm P, 135 ppm of K, and 0.68 percent organic matter.

Ten seed that contained five different concentrations of Mo were planted in three-liter plastic lined cans containing 6.6 pounds (3 kg) of Hebert fine sandy loam soil. The seed were planted on October 7, 1971 and were thinned to five plants per container after ten days. The soil was maintained near field capacity with distilled deionized water.

The soybean plants were harvested after seven weeks of growth. The five plants were cut approximately 2 mm above the soil and were placed in cloth bags and dried in a forced draft oven at 67C. After drying the plants were weighed and after the weights were recorded, they were ground in a stainless steel Wiley mill to pass a 40 mesh screen. The soybean tissue was stored in 2 ounch screw-cap glass specimen bottles.

Chemical Analysis of Soil and Plant Materials

The thiocyanate colorimetric method was used to determine the concentration of Mo in the soil and plant material. Several investigators have used this method for chemical analyses of soil and plant material (43, 49, 74, 76, 80).

A one-half to three gram oven-dry sample of plant material was ashed in a muffle furnace at 500C for six hours in a porcelain crucible. The Mo was dissolved in 10 ml of 2N hydrochloric acid and filtered through Whatman 42 filter paper into a 60 ml Squibb-type separatory funnel. The sample preparation and the determinations of Mo in plant material was described in detail by Chapman and Pratt (23).

The total Mo content of the soils was determined by digestion with 60 percent perchloric acid as described by Reisenauer (76). The digest was filtered and transferred to a 150 ml beaker. The residue was washed with 6.5 N hydrochloric acid and the filtrate was evaporated to dryness on a steam bath. The residue was dissolved in 10 ml of 2N hydrochloric acid and transferred to a 60 ml Squibb-type separatory funnel for the Mo determinations.

The method proposed by Reisenauer (73) and Grigg (37) for extracting "available" Mo in the soil was used. A twenty-five gram sample of oven-dry soil was extracted with acid ammonium oxalate adjusted to pH 3.3. The extracting solution was made by dissolving 24.9 grams of ammonium oxalate and 12.6 grams of oxalic acid in a liter of distilled water. A 1:10 ratio of soil-to-extracting solution was used. The samples were agitated over night on a mechanical shaker. After filtering, a 100-ml aliquot of the filtrate was evaporated to dryness on a steam bath and ignited in a muffle furnace at 450C for four hours to destroy the oxalate. The Molybdenum residue was dissolved in 10 ml of 2N hydrochloric acid and transferred to a 60 ml Squibb-type separatory funnel for the Mo determination.

The thiocyanate chlorimetric procedure developed by Johnson and Arkley (49) as outlined by Chapman and Pratt (23) was used to determine the concentration of Mo in the samples of soil and plant tissue.

Ten ml of a hydrochloric acid-ferric chloride reagent was added to the plant samples in the separatory funnel. This step was omitted for soil samples because sufficient iron was present in the sample to form the ferric-molybdate-thiocyanate complex. A sodium thiocyanate solution was added to form the ferric-molybdate thiocyanate complex.

A reducing agent, stannous chloride, was added to destroy the red complex color and to develop the orange-colored-molybdenum complex. The colored complex was extracted in an organic extractant of equal parts of iso-amyl alcohol and carbon tetrachloride. The optical density of the colored complex was used as a quantitative estimate of the amount of Mo present. Absorbency was measured with a Bausch and Lomb spectronic 20 spectrophotometer set at 470 mu.

A standard curve prepared by using 0, 0.25, 0.5, 1.0, 2.0, 4.0, and 8.0 ppm of Mo was used for obtaining the Mo content of plant, seed and soil samples.

RESULTS AND DISCUSSION

The effects of the different rates and methods of application of Mo on the yield of Bienville soybeans grown on Olivier silt loam, pH 7.0, at the Burden Research Plantation in 1970 are presented in Table 3. The different rates and methods of application of Mo used in this investigation had no significant effect on the yield of soybeans. The yield varied from 24.5 bushels per acre (1646 kg/ha) following the application of the equivalent of 1/4 ounce of Mo per acre (17.5 g/ha) to the soybean plants when they were approximately ten inches tall and 1/4 ounce per acre (17.5 g/ha) when the plants were at the early bloom stage of development to 31.7 bushels per acre (2130 kg/ha) from the application of the equivalent of 1/4 ounce of Mo per acre (17.5 g/ha) applied to the seed prior to inoculation and planting. The yield on the check plot that did not receive an application of Mo was 25.7 bushels per acre (1727 kg/ha).

The total and the ammonium oxalate extractable Mo content of the untreated Olivier silt loam, pH 7.0, was 0.93 ppm and 0.13 ppm respectively.

These data are in agreement with those reported by Grigg (37) in which he did not obtain a significant response to the application of Mo to legumes when the ammonium oxalate extractable content of Mo in the soil exceeded 0.05 ppm and when the pH of the soil was 6.5 or higher. According to Dharmaputra (27) a response to the application of Mo would not be expected if the soil pH + (10 x extractable Mo content) was equal to 7.5 or higher. The Olivier silt loam soil used

Table 3. The effects of the different rates and methods of application of Mo on the yield of Bienville soybeans grown on Olivier silt loam,[1] pH 7.0. Burden Research Plantation 1970.

Identification	Mo Treatments[2/] To Soil	To Seed	Foliar, Stage of Growth: 10 Inches	Early Bloom	Early Pod Set	Total Mo Applied	Yield Average of 5 Replications: bu/acre[3/]	kg/ha[3/]
	oz/acre							
E			1/4	1/4		1/2	24.5	1646
H	8		1/4	1/4	1/4	8 3/4	24.8	1667
G		1/4	1/4	1/4	1/4	1	25.5	1714
I	8	1/4	1/4	1/4	1/4	9	25.5	1714
D			1/4			1/4	25.5	1714
C	8					8	25.6	1720
A						0	25.7	1727
F			1/4	1/4	1/4	3/4	29.3	1969
J	16	1/4	1/4	1/4	1/4	17	20.4	1040
B		1/4				1/4	31.7	2130

[1/] The total and ammonium oxalate extractable Mo contents of the untreated soil were 0.93 ppm and 0.13 ppm respectively.

[2/] Mo as $Na_2MoO_4 \cdot 2H_2O$, 39.65 percent Mo, served as the source of Mo.

[3/] The differences in yield were not statistically significant.

in this experiment had a pH 7.0 and contained 0.13 ppm of ammonium oxalate extractable Mo; therefore, a response to an application of Mo would not be expected.

The effects of the different rates and methods of application of Mo on the yield of Bienville soybean grown on Olivier silt loam, pH 5.8, at the Burden Research Plantation in 1971 are presented in Table 4. The different rates and methods of application of Mo used in this investigation had no significant effect on the yield of soybeans. The yield varied from 31.5 bushels of soybeans per acre (2117 kg/ha) on the soil that did not receive an application of Mo to 39.7 bushels per acre (2668 kg/ha) when Mo was applied to the seed and to the foliage of the soybean plants at three different stages of growth.

The total and the ammonium oxalate extractable Mo content of the untreated Olivier silt loam, pH 5.8, was 2.35 ppm and 0.15 ppm respectively. According to the research conducted by Dharmaputra (27), a response to the application of Mo would be expected on this soil; however, Grigg (37) reported that when the ammonium oxalate extractable Mo content of a soil was 0.15 ppm and when the soil reaction exceeded pH 5.5 a response to the application of Mo would not be expected. A relative large variation in yield occurred within each of the replications and the coefficient of variation was found to be 34 percent. The large coefficient of variation may have been responsible for the failure to obtain a significant response to the application of Mo.

The higher yields obtained on all plots in 1971 as compared to the yields obtained in 1970 were attributed to an earlier planting

Table 4. The effects of the different rates and methods of application of Mo on the yield of Bienville soybeans grown on Olivier silt loam,[1/] pH 5.8. Burden Research Plantation 1971.

Identification	Mo Treatments[2/] To Soil	To Seed	Foliar, Stage of Growth: 10 Inches	Early Bloom	Early Pod Set	Total Mo Applied	Yield Average of 5 Replications bu/acre[3/]	kg/ha[3/]
	oz/acre							
A						0	31.5	2117
B		1/4				1/4	31.7	2130
C	8					8	32.2	2164
J	16	1/4	1/4	1/4	1/4	17	34.2	2298
I	8	1/4	1/4	1/4	1/4	9	34.4	2312
D			1/4			1/4	36.9	2480
F			1/4	1/4	1/4	3/4	37.3	2507
H	8		1/4	1/4	1/4	8 3/4	37.6	2527
E			1/4	1/4		1/2	37.8	2540
G		1/4	1/4	1/4	1/4	1	39.7	2668

[1/] The total and the ammonium oxalate extractable Mo contents of the untreated soil were 2.35 ppm and 0.14 ppm respectively.

[2/] Mo as $Na_2MoO_4 \cdot 2H_2O$, 39.65 percent Mo, served as the source of Mo.

[3/] The differences in yield were not statistically significant.

date and better moisture conditions that occurred throughout the 1971 growing season.

The effects of different rates and methods of application of Mo on the concentration of Mo in the seed of Bienville soybeans grown on Olivier silt loam, pH 7.0, at the Burden Research Plantation in 1970 are presented in Table 5. The concentration of Mo in the seed of soybean plants varied from 5.67 ppm on the untreated soil to 29.75 ppm in the seed of plants that received a total of 9 ounces of Mo per acre (631 g/ha) applied as a combination of a soil, seed and foliar applications. The data indicate that the application of Mo at a rate equivalent to 1/4 ounce (17.5 g/ha) and 1/2 ounce (35 g/ha) of Mo to the foliage, 1/4 ounce (17.g 6/ha) to the seed, or 8 ounces (561 g/ha) to the soil per acre did not result in a significant increase in the concentration of Mo in the soybean seed. The concentrations of Mo in the seed following the application of Mo to the foliage, seed and soil were 6.80, 7.06, 8.08, and 8.73 ppm respectively. The concentration of Mo in the seed of the check treatment that did not receive an application of Mo was 5.67 ppm.

A significant increase in the Mo concentration in the soybean seed was obtained when Mo was applied to both the seed and foliage of the soybean plants at three stages of growth. A significant increase in the concentration of Mo in the seed was obtained when the Mo was applied to the foliage of the soybean plants at three stages of growth. The Mo concentration in the seed from these two treatments were 17.05 and 18.54 ppm respectively. Applying a foliar application of 1/4 ounce (17.5 g/ha) of Mo per acre to the foliage of soybean plants at the early pod set stage of growth in addition to applying 1/4 ounce

Table 5. The effects of different rates and methods of application of Mo on the concentration of Mo in the seed of Bienville soybeans grown on Olivier silt loam,[1] pH 7.0. Burden Research Plantation 1970.

Identification	Mo Treatments[2] To Soil	To Seed	Foliar, Stage of Growth: 10 Inches	Early Bloom	Early Pod Set	Total Mo Applied	Concentration of Mo in Seed, Average of 5 Replications
	oz/acre						ppm
A						0	5.67 a[3]
D			1/4			1/4	6.80 a
E			1/4	1/4		1/2	7.06 a
B		1/4				1/4	8.08 a
C	8					8	8.73 a
G		1/4	1/4	1/4	1/4	1	17.05 b
F			1/4	1/4	1/4	3/4	18.64 b
J	16	1/4	1/4	1/4	1/4	17	24.75 c
H	8		1/4	1/4	1/4	8 3/4	26.71 c
I	8	1/4	1/4	1/4	1/4	9	29.75 c

1/The total and the ammonium oxalate extractable Mo content of the untreated soil were 0.93 ppm and 0.13 ppm respectively.

2/Mo as $Na_2MoO_4 \cdot 2H_2O$, 39.65 percent Mo, served as the source of Mo.

3/All means which are followed by a letter in common do not differ significantly at the 5% level of probability.

(17.5 g/ha) of Mo per acre when plants were ten inches tall and again at the early bloom stage of growth increased the concentration of Mo in the soybean seed from 7.06 to 18.64 ppm. Further significant increases in the concentration of Mo in the seed were obtained when a Mo application was applied to the soil in addition to the application of Mo to the seed and to the foliage at three stages of growth. The highest concentration of Mo in the seed was obtained when Mo was applied as a combination of soil, seed, and foliar at three stages of growth.

The data show that the application of Mo to the foliage of soybean plants at the early pod set stage of growth had a greater influence on the concentration of Mo in the soybean seed than did the application of Mo applied at any other time or method. Since Mo can be toxic to cattle, these Mo treatments that result in high concentration of Mo in the seed should only be used on fields intended for use as seed.

The data also show that method of application had a much greater influence on the concentration of Mo in the soybean seed than did the rate of application.

The effect of different rates and methods of application of Mo on the concentration of Mo in the seed of Bienville soybeans grown on Olivier silt loam, pH 5.8, at the Burden Research Plantation in 1971 are presented in Table 6. The concentration of Mo in the seed of soybean plants varied from 2.24 ppm on the untreated soil that did not receive an application of Mo to 16.95 ppm in the seed of plants that received a total of 17 ounces (1192 g/ha) of Mo applied as a combination of soil, seed and foliar applications.

Table 6. The effects of the different rates and methods of application of Mo on the concentration of Mo in Bienville soybean seed grown on Olivier silt loam,[1/] pH 5.8. Burden Research Plantation 1971.

Identification	Mo Treatments[2/] To Soil	To Seed	Foliar, Stage of Growth: 10 Inches	Early Bloom	Early Pod Set	Total Mo Applied	Concentration of Mo in Seed, Average of 5 Replications
	oz/acre						ppm
A						0	2.24 a[3/]
D			1/4			1/4	2.71 a
C	8					8	2.93 a
B		1/4				1/4	2.99 a
E			1/4	1/4		1/2	4.60 a
G		1/4	1/4	1/4	1/4	1	5.78 ab
F			1/4	1/4	1/4	3/4	9.26 b
H	8		1/4	1/4	1/4	8 3/4	9.37 b
I	8	1/4	1/4	1/4	1/4	9	14.33 c
J	16	1/4	1/4	1/4	1/4	17	16.95 c

1/ The total and ammonium oxalate extractable Mo in the untreated soil was 2.35 ppm and 0.15 ppm respectively.

2/ Mo as $Na_2MoO_4 \cdot 2H_2O$, 39.65 percent Mo, served as the source of Mo.

3/ All means which are followed by a letter in common do not differ significantly at the 5% level of probability.

The data show that the application of Mo as a foliar, seed, soil, or seed and foliar treatment did not significantly increase the concentration in the seed obtained from the check treatment that did not receive an application of Mo. However, there was a definite trend for the concentration of Mo in the soybean seed to increase when Mo was applied as a seed, a soil, or a foliar application.

The data also show that the concentration of Mo in soybean seed was not significantly different for the treatments that received three foliar applications, three foliar plus a soil application, and three foliar plus a seed application. Three foliar applications of Mo made at different stages of growth significantly increased the concentration of Mo in the seed of soybeans over the concentration of Mo in the seed of the treatments that received Mo as a single foliar, two foliar, a seed, or a soil application. The Mo concentration in the seed of the treatment where Mo was applied to the soil and to the foliage at three stages of growth did not differ significantly from the treatment where Mo was applied to the foliage at three stages of growth. The concentration for the soil and foliar treatment and the foliar treatment was 9.37 ppm and 9.26 ppm respectively.

The concentrations of Mo in the seed of soybeans harvested from treatments that had applications of Mo as a soil, seed and three foliar at different stages of plant growth were significantly higher than the other eight Mo treatments used. The application of 16 ounces (1122 g/ha) of Mo per acre did not significantly increase the concentration of Mo in the seed over applications of 8 ounces (561 g/ha) in this experiment.

These data indicate as did the 1970 data that the application of Mo to the foliage of soybean plants at the early pod set stage of growth had a greater influence on the concentration of Mo in the seed of Bienville soybean plants than did the application of Mo applied at any other time or method.

The effects of different rates and methods of application of Mo on the concentration of Mo in the seed of Bienville soybeans grown on Olivier silt loams at the Burden Research Plantation in 1970 and 1971 are presented in Table 7. All Mo treatments that received an application of Mo to the foliage when the soybean plants were in the early pod set stage of growth had significantly higher concentrations of Mo in the seed than treatments that did not receive this late foliar application of Mo.

The data show that the application of Mo as a combination of the following methods, soil, seed, and foliar at three stages of growth resulted in the highest concentration of Mo in the soybean seed. These treatments gave a six-fold increase in the concentration of Mo in soybean seed over the check that did not receive an application of Mo.

The data also indicate that the method of application is more important than the rate of application of Mo for increasing the Mo concentration of soybean seed.

The effects of different rates and methods of application of Mo and the influence of pH on the concentration of Mo in the seed of Bienville soybeans grown on Olivier silt loam are shown in Figure 1. The concentration of Mo in the seed for each rate and method of application of Mo grown on the Olivier silt loam, pH 7.0, was over two-fold more than the concentration of Mo in the seed from the same rate and method of application of Mo grown on the Olivier silt loam,

Table 7. The effects of the different rates and methods of application of Mo on the average concentration of Mo in Bienville soybean seed grown on Olivier silt loam, pH 7.0 and pH 5.8. Burden Research Plantation 1970 and 1971.

Identification	Mo Treatments[2] To Soil	To Seed	Foliar, Stage of Growth: 10 Inches	Early Bloom	Early Pod Set	Total Mo Applied	Concentration of Mo in Seed, Average of 2 Years
	oz/acre						ppm
A						0	3.95 a[2]
D			1/4			1/4	4.75 a
B		1/4				1/4	5.53 a
E			1/4	1/4		1/2	5.82 a
C	8					8	5.83 a
G		1/4	1/4	1/4	1/4	1	11.48 b
F			1/4	1/4	1/4	3/4	13.95 b
H	8		1/4	1/4	1/4	8 3/4	18.03 c
J	16	1/4	1/4	1/4	1/4	17	20.85 cd
I	8	1/4	1/4	1/4	1/4	9	22.02 d

[1]Mo as $Na_2MoO_4 \cdot 2H_2O$, 39.65 percent Mo, served as the source of Mo.

[2]All means which are followed by a letter in common do not differ significantly at the 5% level of probability.

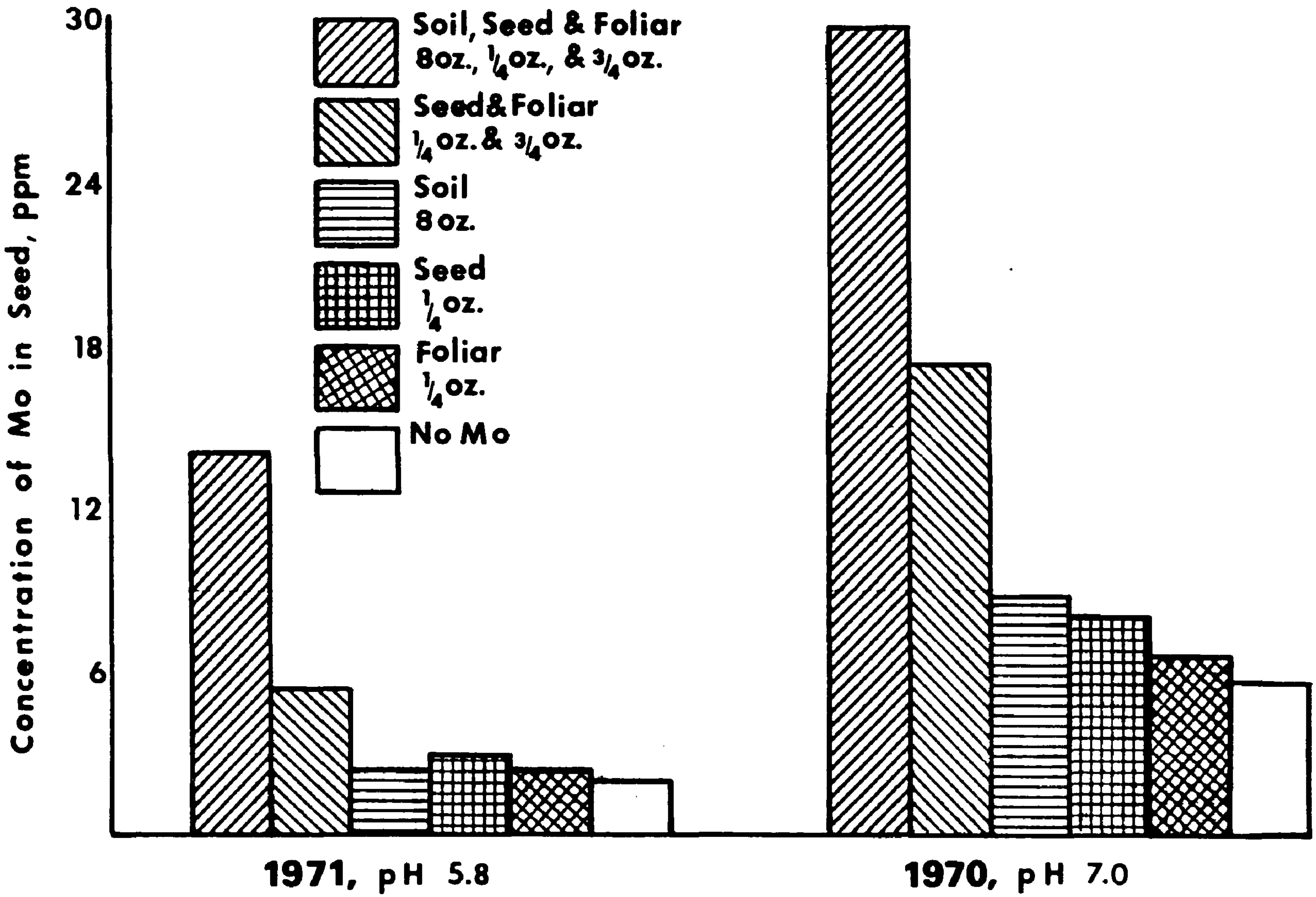

Figure 1. The effects of different rates and methods of application of Mo on the concentration of Mo in the seed of Bienville soybeans grown on Olivier silt loam in 1970 and 1971.

several treatments receiving Mo in 1971. Since the Olivier silt loam site used in 1970 had a pH 7.0 and the site used in 1971 had a pH 5.8, it can not be discerned from these experiments whether differences were due to environmental factors or to pH. However, based on the work of several other investigators (6, 14, 27, 84) much of the difference may have been due to soil reaction.

The influence of the concentration of Mo in the seed on the yield of Bienville soybeans grown on Olivier silt loam, pH 6.9, at the Burden Research Plantation in 1971 are presented in Table 8. The yield varied from 22.1 (1485 kg/ha) bushels per acre from seed containing 0.17 ppm of Mo to 30.1 (2023 kg/ha) bushels per acre from seed containing 30.19 ppm of Mo. The yield from seed containing different concentrations of Mo did not differ statistically at the five percent level of probability. The Olivier silt loam soil contained 0.87 ppm total Mo and 0.20 ppm of ammonium oxalate extractable Mo. Yield response would not be expected from different Mo concentrations in the seed of soybean grown on this soil.

The influence of the concentration of Mo in the seed of Bienville soybeans on the production of dry matter of plants grown on Hebert fine sandy loam, pH 4.2, in the greenhouse in 1971 are presented in Table 9. The dry matter production varied from 1.61 grams per pot from seed containing 0.17 ppm Mo to 2.74 grams per pot from seed containing 18.30 ppm Mo. The production of dry matter was significantly lower from the seed that contained 0.17 ppm Mo. When the concentration of Mo in the seed was increased from 0.17 ppm to 0.52 ppm, a significant increase in the production of dry matter was recorded. However, when the

Table 8. The influence of the concentration of Mo in the seed on the yield of Bienville soybeans grown on an Olivier silt loam,[1/] pH 6.9. Burden Research Plantation 1971.

Identification	Concentration of Mo in Seed	Yield Average of 5 Replications	
	ppm	bu/a	kg/ha
S-1	0.17	22.1	1485
S-2	0.29	2/	2/
S-3	0.52	24.6	1653
S-4	0.61	27.9	1875
S-5	0.96	28.9	1942
S-6	5.00	28.9	1942
S-7	20.02	29.5	1982
S-8	18.30	26.7	1794
S-9	30.19	30.1	2023
S-10	4.27[3/]	25.9	1740

1/The total and ammonium oxalate extractable Mo in the untreated soil were 0.875 ppm and 0.20 ppm respectively.

2/Yields were not obtained due to an inadequate stand.

3/Seed were treated with 1/4 ounce of Mo as $Na_2MoO_4 \cdot 2H_2O$, 39.65 percent Mo, per acre.

Table 9. The influence of the concentration of Mo in the seed of Bienville soybeans on the production of dry matter of plants grown on a Hebert fine sandy loam,1/ pH 4.2 in the greenhouse 1971.

Seed Identification Code	Concentration of Mo in Seed	Dry Matter2/ Average of 5 Replications
	ppm	g/pot
2	0.17	1.61 a3/
3	0.52	2.57 b
4	0.96	2.58 b
1	4.27 4/	2.63 b
5	18.30	2.74 b

1/The total and ammonium oxalate extractable Mo in the untreated soil were 0.25 ppm and 0.012 ppm respectively.

2/The production of dry matter was measured after 7 weeks of growth.

3/All means which are followed by a letter in common do not differ significantly at the 5% level of probability.

4/Mo as $Na_2MoO_4 \cdot 2H_2O$, 39.65 percent of Mo, was applied at a rate equivalent to 1/4 ounce per acre to the seed before planting.

concentration of Mo was increased above 0.52 ppm, further significant increases in the production of dry matter were not obtained. The data suggest that a concentration in the seed of approximately 0.5 ppm of Mo is sufficient for the production of soybeans.

The relative growth of soybean plants produced from seed that contained 18.3 ppm of Mo (number 5), 0.17 ppm of Mo (number 2), and seed that contained 4.27 ppm of Mo that were treated with Mo at a rate equivalent to 1/4 ounce per acre (number 1) are shown in Figure 2. A comparison of the growth pattern in Figure 2 indicates a superiority in growth for plants grown from seed that contained more than 0.17 ppm.

In Figure 3 the relative growth of soybean plants produced from seed that contained 4.27 ppm Mo and treated with 1/4 ounce of Mo per acre (number 1) were compared to plants grown from seed that contained 0.17 ppm Mo (number 2), 0.52 ppm Mo (number 3), 0.96 ppm Mo (number 4), and 18.30 ppm Mo (number 4). A comparison of the growth pattern in Figure 3 indicates that plants grown from the seed that contained 0.17 ppm had a slower growth rate.

The influence of the concentration of Mo in the seed of Bienville soybeans on the concentration of Mo in the plant tissue grown on Hebert fine sandy loam, pH 4.2, in the greenhouse are presented in Table 10. The concentration of Mo in the plant tissue varied from 0.07 ppm to 3.91 ppm for the plants grown from seed containing 0.17 and 18.3 ppm of Mo respectively. Plants grown from seed containing 0.17 ppm Mo, 0.52 ppm Mo and 0.92 ppm Mo did not differ statistically in the concentration of Mo in the plant tissue. The concentration of Mo in the tissue of soybean plants was significantly increased when plants were grown with seed that contained 4.27 ppm Mo treated with 1/4 ounce of

Figure 2. The relative growth of soybean plants produced from seed that contained 18.3 ppm of Mo (number 5), 0.17 ppm of Mo (number 2), and seed that contained 4.27 ppm of Mo that were treated with Mo at a rate equivalent to 1/4 ounce per acre (number 1).

Figure 3. The relative growth of soybean plants produced from seed that contained 4.27 ppm of Mo and treated with 1/4 ounce of Mo per acre (number 1) compared to plants grown from seed that contained 0.17 ppm of Mo (number 2), 0.52 ppm of Mo (number 3), 0.96 ppm of Mo (number 4), and 18.30 ppm of Mo (number 5).

Table 10. The influence of concentration of Mo in the seed of Bienville soybeans on the concentration of Mo in plants grown on Hebert fine sandy loam,1/ pH 4.2, in the greenhouse 1971.

Seed Identification Code	Concentration of Mo in Seed	Concentration of Mo in Plant Tissue, Average of 5 Replications
	ppm	ppm
2	0.17	0.07 a3/
3	0.52	0.26 a
4	0.96	0.41 a
1	4.274/	1.18 b
5	18.30	3.91 c

1/The total and ammonium oxalate extractable Mo in the untreated soil was 0.25 ppm and 0.012 ppm respectively.

2/The concentration of Mo in the plant tissue was measured after seven weeks of growth.

3/All means which are followed by a letter in common do not differ significantly at the 5% level of probability.

4/Mo as $Na_2MoO_4 \cdot 2H_2O$, 39.65 percent of Mo, was applied at a rate equivalent to 1/4 ounce per acre to the seed before planting.

Mo per acre (17.5 g/ha). A further statistically significant increase in the concentration of Mo in the plant tissue was obtained in soybeans grown from seed that contained 18.30 ppm Mo.

The data in Table 10 show that the Mo concentration in soybean plants can be increased by the concentration of Mo in the seed when plants are grown on an acid soil, pH 4.2. The data also indicate that the Mo requirements of soybean plants can be supplied by the Mo concentration in the seed.

SUMMARY AND CONCLUSION

Field and greenhouse investigations were conducted during a two-year period, 1970 and 1971, to determine the effects of different rates and methods of applying Mo on the yield, the production of dry matter, and the concentration of Mo in the tissue of Bienville soybean plants, Glycine max (L.) Merr., grown on Olivier silt loam and Hebert fine sandy loam. Investigations were also conducted in the field and in the greenhouse to determine the influence of different levels of Mo in the seed of Bienville soybeans on the yield and on the concentration of Mo in the tissue of plants grown on an Olivier silt and on an Hebert fine sandy loam.

Mo applied to the soil, to the seed, to the foliage and certain combinations of these treatments, did not significantly increase the yield of soybeans grown in the field on Olivier silt loam at pH 7.0 and pH 5.8.

The concentration of Mo in the seed was significantly increased by the application of Mo. On the Olivier soil, pH 7.0, the concentration of Mo varied from a low of 5.67 ppm when no Mo was applied to 29.75 ppm when Mo was used as a combination of a seed, soil, and foliar applications. On the Olivier silt loam, pH 5.8, the concentration of Mo in the seed was increased from 2.24 ppm where no Mo was applied to 16.95 ppm when the combination of soil, seed, and foliar applications was used. Seed produced in 1970 on the soil, pH 7.0, contained over twice as much Mo as did seed produced in 1971 on the soil, pH 5.8. It cannot be discerned from these experiments whether differences were due to environmental factors or to pH. The time and method of application of Mo affected the concentration of Mo in the seed more than did the rate used. Mo applied to the foliage of the soybean plants at the early pod set stage of growth resulted in seed with the highest concentration of Mo.

Seed that contained different concentrations of Mo had no significant effect on the yield of soybeans grown on an Olivier silt loam, pH 6.9 under field conditions.

Increasing the concentration of Mo in the seed significantly increased the dry matter production and the concentration of Mo in the tissue of soybean plants grown in the greenhouse on Hebert fine sandy loam, pH 4.2. Seed that contained 0.52 ppm of Mo produced significantly larger amounts of the dry matter than did seed that contained 0.17 ppm of Mo. Increasing the concentration of Mo in the seed above 0.52 ppm Mo did not result in a further significant increase in dry matter production. Plants grown from seed that contained 18.3 ppm Mo had a significantly higher concentration of Mo in the tissue than did plants grown from seed that contained 4.27 ppm of Mo and treated with 1/4 ounce of Mo per acre (17.5 g/ha). The concentration of Mo in the tissue was significantly lower for plants grown from seed that contained 0.17 ppm, 0.52 ppm, and 0.96 ppm of Mo that for plants grown from seed that contained 4.27 ppm of Mo and treated with 1/4 ounce of Mo per acre (17.5 g/ha).

The data obtained in the greenhouse experiment indicated that seed containing approximately 0.5 ppm of Mo was sufficient to meet the requirement of soybean plants growing on Hebert fine sandy loam, pH 4.2.

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VITA

Olen D. Curtis, the son of Alec W. and Gussie M. Curtis, was born in Attala County near Zama, Mississippi on August 3, 1927. He was reared on a cotton and dairy farm where he received considerable experience in general farm production.

He received both elementary and secondary schooling at Zama Vocational High School, Zama, Mississippi where he was valedictorian of his class that graduated in 1945. After graduation he enlisted in the United States Navy and served in the Pacific Theater from April 1945 to October 1947.

Upon completing his military obligation, Mr. Curtis leased a cotton, corn and hay farm and farmed in 1948. In January 1949, he entered Mississippi State University, State College, Mississippi where he received a Bachelor of Science degree in Agronomy-Soils in 1952 and a Master of Science degree in Agronomy-Seed Production and Processing in 1953. His thesis was entitled "Chemical Desiccation of Small-Seeded Legume Crops for Seed Harvesting."

After graduation he was employed as seed analyst by Tyner-Petrus Seed Company located in West Monroe, Louisiana. On August 2, 1954, he joined the staff of the Louisiana State University Agricultural Experiment Station at the Southeast Louisiana Dairy and Pasture Experiment Station, Franklinton, Louisiana. He was engaged in fertilization, variety testing and management research with pasture and forage crops. He transferred to the Department of Agronomy in 1959 where he was responsible for the forage testing program for one year. During this time he enrolled in some graduate courses. He then transferred to Springhill, Louisiana to do research on the use of paper mill effulent as a source of irrigation water for corn, rice, cowpeas, and pasture crops. This work was financed by International Paper Company, Springhill, Louisiana.

In 1963 Mr. Curtis transferred to the Louisiana Cooperative Extension Service as an Associate Specialist to lead the Extension educational program in soil management, soil fertility, and seed improvement.

He was granted Sabbatical leave in 1969-70 to complete the course work toward the Doctor of Philosophy degree in Agronomy-Soil Fertility.

He is a member of the Louisiana Association of Agronomists, Alpha Zeta, Gamma Sigma Delta and Soil Conservation Society of America. He also serves as the Secretary-Treasurer to the Louisiana Plant Food Educational Society, Inc. He is active in the Baptist Church, The Woodlawn High School Dad's Club, and local Parent Teacher Organizations.

He is married to the former Mildred L. Mangrum. They have three daughters and two sons.

He is scheduled to receive the Doctor of Philosophy degree in Agronomy-Soil Fertility in December 1972.

EXAMINATION AND THESIS REPORT

Candidate: Olen D. Curtis

Major Field: Agronomy

Title of Thesis: The Effects of Application of Molybdenum and Concentration of Molybdenum in the Seed on the Yield and the Concentration of Molybdenum in the Tissue of Soybeans, Glycine Max (L.) Merr.

Approved:

A. L. Caldwell
Major Professor and Chairman

Max Goodrich
Dean of the Graduate School

EXAMINING COMMITTEE:

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Date of Examination:

November 28, 1972